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U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

TIME OF FLIGHT AND BALLISTIC COEFFICIENT

1. OBJECTIVE

The objective of this MTP is to describe techniques for measuring time of flight and calculating form factor and ballistic coefficient.

2. BACKGROUND

The ballistic coefficient is a value that indicates the ability of a projectile to overcome air resistance, and is therefore essential to constructing range tables and velocities along the trajectory. To determine ballistic coefficient, it is necessary to first determine the projectile velocity at a given point (muzzle velocity, for example), and the time of flight between the muzzle and one or more points downrange. The ballistic coefficient is expressed by the formula:

$$C = \frac{W}{id^2}$$

where: W is the weight of the projectile in pounds.
d is the diameter of the projectile in inches.
i is an empirical factor, called the form factor, which compares the "streamlining" (actually the drag coefficient, K_D) of the projectile under consideration with that of a particular standard drag coefficient, K_{D_S}, at the same velocity. The form factor is given by the equation,

$$i = \frac{K_D}{K_{D_S}}$$

Projectiles are categorized according to their basic shape (reference 4E), each shape having a certain drag function. The relationship between drag coefficient K_D, and drag function, G, is given by the equation,

$$G = K_D P_s V.$$

Here, P_s is standard sea level air density and V is the projectile velocity. Typical designations for the various categories of drag functions are G_1, $G_{2.1}$, $G_{5.1}$, etc., each category being a code for a basic shape of projectile. To extrapolate the velocity from one point on the trajectory (e.g., instrumental velocity) to another point (e.g., muzzle velocity or striking velocity) it is necessary to know the ballistic coefficient and the form factor relative to a standard projectile drag function.

Since form factors, and therefore ballistic coefficients, vary along the trajectory as the velocity of the projectile decreases, values must be

*With MTP 4-2-805, supersedes Interim Pamphlet 80-15.

specified for a particular velocity level. Table I illustrates values for three projectiles traveling at muzzle velocity.

Table I. Ballistic Values of Typical Projectiles at Muzzle Velocity

Projectile Type and Caliber	Ballistic Coefficient	Form Factor	Drag Function
90-mm AP	1.59	1.19	G1
90-mm HEAT	1.78	1.65	G6.1
155-mm HE	2.056	1.02	G5.1

3. REQUIRED EQUIPMENT

Equipment and Facilities as required by referenced MTP's.

4. REFERENCES

A. TM 9-1860-7, Operation and Organization Maintenance; Field Sky Screen and Counter Chronograph.
B. AMCP 706-107, Engineering Design Handbook, Elements of Armament Engineering, Part 2, Ballistics.
C. Cantey, W. E., Analytical Laboratory Report on Tables of Drag Coefficients, Aberdeen Proving Ground, Md., Development and Proof Services Report 567, May 1962.
D. Hayes, Thomas J., Elements of Ordnance, John Wiley and Sons, January 1938.
E. Heppner, L., Method for Calculating Exterior Ballistic Trajectories on a Bendix G15 Electronic Computer, Aberdeen Proving Ground, Md., Development and Proof Services Report 416, January 1962.
F. Herrmann, Ernest E., Exterior Ballistics, U. S. Naval Institute, 1935.

NOTE: G through K are Aberdeen Proving Ground, Md., Ballistic Research Laboratories Reports by Hitchcock, H.P.

G. No. 564, Table of Form Factors of Projectiles, October 1951.
H. No. 620, Aerodynamic Data for Spinning Projectiles, October 1946.
I. No. X-111, Aerodynamic Nomenclature and Formulas, Conversion Factors, and Drag Functions, 18 July 1938.
J. No. X-113, Resistance and Stability of Projectiles: Experimental Methods and Details of Computations, 1 December 1932.
K. Technical Note No. 745, Bibliography of Tables of Drag and Related Functions, October 1952.
L. McShane, Kelly, Reno, Exterior Ballistics, Univ. of Denver Press, 1953.
M. Tolen, J. A., Minimization of Solenoid Spacing Leading to Miniaturization of Solenoid Structures, Aberdeen Proving Ground, Md.,

Development and Proof Services Report 495, February 1962.
N. MTP 3-2-601, Vertical Target Accuracy, Dispersion, and Time of Flight.
O. MTP 4-1-005, The Doppler Velocimeter.
P. MTP 4-2-800, Physical Measurement of Projectiles.
Q. MTP 4-2-805, Projectile Velocity Measurements.
R. MTP 4-2-816, Photographic Instrumentation for Trajectory Data.

5. SCOPE

5.1 SUMMARY

This MTP describes methods of determining time of flight, form factor, and ballistic coefficient for projectiles having essentially flat trajectories.

5.2 LIMITATIONS

This MTP does not cover means of obtaining ballistic coefficients for high-angle-of-fire weapons. It also does not cover velocity measurements (MTP 4-2-805), accuracy and dispersion (MTP 3-2-601), or computation of range tables (which are performed by U. S. Army Aberdeen Research and Development Center - ARDC).

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Test Design Criteria

a. Sample Size - The number of rounds to be fired to determine ballistic coefficients is dependent upon a number of factors; principally, the length of range covered by detecting devices, the number of detecting devices that can be used for a given round, and the number of incremental charges that the projectile may have. Since the ballistic coefficient differs at the various velocities for the same projectile, all useful velocities must be covered. The test director must obtain guidance on the number of rounds to fire and zone charges to use from the ballisticians at his agency who will reduce the data or from ARDC, as applicable.

b. Selection of Instrumentation - Detecting devices and time measuring equipment should be selected from those described in MTP 4-2-805 and MTP 4-2-816. The use of the Doppler velocimeter for obtaining data that can be used for determination of the ballistic coefficient is discussed in MTP 4-1-005.

c. Linear Measurements - Techniques for making linear measurements are described in MTP 4-2-805.

d. Introduction of Errors - On rounds with extremely low drag or when firing to close-in targets, where there is a relatively small change in time of flight, the errors introduced by sky screens can be serious. In such cases the use of sky screens is not recommended.

6.1.2 Weapon

Record the weapon and tube model and serial numbers as well as pertinent tube wear measurements.

6.1.3 Pretest Inspection of the Projectile

Determine and record the physical measurements of the projectile in accordance with the procedures outlined in MTP 4-2-800, to include:

a. Projectile model, serial, and lot number
b. Projectile weight, to nearest 0.01 pound
c. Diameter of projectile, in inches

6.2 TEST CONDUCT

The ballistic coefficient can be determined by measuring muzzle velocity by convenient means and, additionally, measuring the time of flight to a vertical target. The time of flight can be determined by means of sky screens or by use of a special target that includes wire mesh as a projectile detector. Sky screens may be used not only at the target but at intermediate points along the trajectory to obtain additional data. Testing is conducted as follows:

a. Position detection and time measuring equipment as described in MTP 4-2-805.
b. Measure and record distance from muzzle to projectile detecting devices, distance between detectors, and distance to vertical target to the nearest 0.01 foot.
c. Conduct firing, and for each round fired, record the following:

1) Projectile serial number.
2) Time of day.
3) Propellant type and lot.
4) Propellant weight to nearest 0.01 ounce.
5) Tube round number.
6) Tube elevation, measured with quadrant.
7) Azimuth of line of fire, clockwise from south to nearest 0.05 degree.
8) Time required for the projectile to traverse the distance between the detectors and the time of flight to the vertical target.
9) Velocity of wind (measured with anemometer at the firing site).
10) Wind direction to nearest 5 degrees.
11) Temperature of the air (by means of dry bulb thermometer placed in shade at firing site) to nearest 1°F.

d. Record the barometric pressure and relative humidity determined by the meteorological measurement station or the weather station at intervals of one hour during the firing.

6.3 TEST DATA

6.3.1 Preparation for Test

Record the following:

a. The weapon and tube model serial numbers and pertinent tube wear measurements.
b. Projectile model, serial number, and lot number.
c. Projectile weight to the nearest 0.01 pound.
d. Diameter of projectile, in inches.

6.3.2 Test Conduct

Record the following:

a. Distance from weapon muzzle to projectile detecting devices, between detecting devices, and to vertical target to 0.01 foot.
b. Time of day.
c. Propellant type and lot.
d. Propellant weight to nearest 0.01 ounce.
e. Tube round number.
f. Tube elevation, in mils.
g. Azimuth of line of fire (clockwise from south to nearest 0.05 degree).
h. Time of flight of projectile to include time between all detectors.
i. Wind velocity, in mps.
j. Wind direction to the nearest 5 degrees.
k. Air temperature at firing site to nearest 1°F.
l. Barometric pressure, in millibars.
m. Relative humidity, in percent.

6.4 DATA REDUCTION AND PRESENTATION

a. The density of the air, in Kg/m^3 required for each round, should be calculated to the nearest 0.1 percent of standard based upon the temperatur barometric pressure, and humidity at the firing range.
b. Calculate the instrumental velocity in accordance with procedures outlined in MTP 4-2-805.
c. Reduce the data of paragraph 6.3 according to procedures of Appendix A.

NOTE: In certain tests sponsored by ARDC, the customer performs the data reduction.

APPENDIX A

COMPUTATION OF BALLISTIC COEFFICIENT AND FORM FACTOR

The form factor of a projectile can be computed when the following data are known. The information is obtained in connection with the test program before and at the time of fire.

Symbol	Quantity	Units
W	Weight of projectile (in flight)	lb.
d	Diameter of projectile	in.
A	Azimuth of line of fire (clockwise from south)	deg
ϕ_o	Angle of elevation of gun muzzle (from horizontal)	mil
S	Angle of boresight to target (from horizontal)	mil
B	Azimuth of direction from which the wind is blowing (clockwise from south)	deg
w	Velocity of wind (at firing site)	mps
T	Temperature of air (at firing site)	^oC
σ	Density of the air (at firing site)	kg/m^3
X_j	Horizontal distance along line of fire (from muzzle to predetermined points)	ft.
V_j	Velocity of projectile (at one of the specified distances or at intervals of time or distance)	fps
t_j	Time of flight of projectile (at specified horizontal distances or intervals during flight referred to a known projectile position near the muzzle)	sec.

Some of the quantities above may need to be modified and other quantities calculated. These are:

w_x	Range component of wind (a + component indicates a wind blowing from the weapon toward the target)	fps
a	Ratio of actual velocity of sound to that under standard conditions.	-
ρ	Ratio of actual air density to standard air density	-

(compatible with computational procedures)

ϵ	Superelevation fired	mil
h_j	Height of projectile above horizontal plane through gun muzzle	ft.
U_j	Siacci velocity	fps

Equations to obtain these quantities are given below.

$$\epsilon = \text{[illegible]}_o - S \qquad (1)$$

$$w_x = 3.2808\ w \cos \left[(B-A) - 180°\right] \qquad (2)$$

$$a^2 = (273 + T)\ /288 \qquad (3)$$

$$\rho = 0.831\sigma \qquad (4)$$

$$U_j = (V_j - w_x)\ /a \qquad (5)$$

The height of the projectile, h_j, is either known (reduced velocimeter data) or may be determined, when required, by calculating the projectile path from muzzle to impact after a ballistic coefficient to target position has been determined.

The computations are now continued by use of equations derived by Siacci for flat fire (usable up to an ϵ of approximately 5° (1° = 17.78 mils)) and Siacci space and time functions, S(U) and T(U), based on a predetermined drag function, [illegible]. The particular drag function to be chosen is the one that can be expected to best describe the drag of the test projectile based on a comparison of the outside contour of the test round with the respective contours of those projectiles used in the determination of the numbered drag functions. Boattail and shape of head are the most important factors to consider in choosing the drag function to be used. Seven of such Siacci functions have been tabulated against U. Other drag functions are available but, in these cases, the Siacci functions and ensuing computations must be generated on high speed digital machines. Reference 4J contains sketches of the projectiles for which Siacci functions have been computed. Available space and time tables are listed in Reference 4K.

Having chosen the drag function to be used in the calculations, the equations and procedures are commenced. These differ slightly depending upon the type of instrumentation used.

The basic equations are applicable to data recorded by use of velocity sensors near the muzzle and a wire mesh screen or other sensing instrument at the target distance. The instrumental velocity (only velocity measured) is assumed to be at a point midway between the two velocity measuring detectors.

The time of flight to target, t_2, from the first detector is then corrected to the same zero base by assuming that the time at the midpoint between velocity detecting devices is one-half of the total measured time, t_v, between devices:

$$t = t_2 - t_1 \tag{6}$$

where $t_1 = t_v/2$

The horizontal distance is found by

$$X = X_2 - X_1 \tag{7}$$

The subscripts 1 and 2 refer to initial base and target positions, respectively.

It is necessary, next, to estimate a ballistic coefficient, C_G, on the basis of previous information or, lacking that, to divide the diameter squared, d^2, by projectile weight, W, for an estimated value.

The following equations can then be solved.

$$S(U_2) = S(U_1) + (X - w_x t)\rho / C \tag{8}$$

$$t_c = C \sec \epsilon \left[T(U_2) - T(U_1)\right] / \rho a \tag{9}$$

where t_c is the calculated time of flight. This is compared with t of (6). If t_c differs from t, another C_G is estimated and the solution repeated until $t - t_c = 0$. In making new estimates of C, it is to be noted that increasing the value of C decreases the value of t_c. When the difference $t - t_c$ is zero, the value of C which was used is taken as the ballistic coefficient (based on the chosen drag function) of the test projectile under standard meteorological conditions for that range from muzzle.

If velocity is measured at the target, $X_{1,\,2}$ and $t_{1,\,2}$ are determined for the points at which the velocity is known (midpoint velocity) and C may be determined by

$$C = (X - w_{xt})\ \rho\ /\ S(U_2) - S(U_1) \tag{10}$$

or by

$$C = t\ \rho a\ /\left[T(U_2) - T(U_1)\right]\ \sec \epsilon \tag{11}$$

If velocity and/or time is measured at intermediate points along the flight

path by any instrumentation method, C_G may be determined for these intermediate points by slightly modifying the above equations (Reference 4I).

First, X, wherever it appears, must be replaced by X' given by

$$(X')^2 = (X_2 - X_1)^2 + (h_2 - h_1)^2 \qquad (12)$$

where the subscript 2 designates values determined at chosen points along the flight path while subscript 1 remains the designation for the data point nearest the muzzle.

Sec ϵ and a are deleted from equations (9) and (11).

An initial angle, α, is determined by

$$\alpha = \epsilon - \tan^{-1} (h_2 - h_1) / (X_2 - X_1) \qquad (13)$$

and the X' terms of equations (8) and (10) are multiplied by $a \cdot \cos \alpha$.

Procedures are then identical to those described above.

If velocimeter data are available, the C_G may be determined for any two points chosen along the flight path. Any of the modified equations may be used except that α of equation (13) becomes

$$\alpha' = \theta_1 - \tan^{-1} (h_2 - h_1) / (X_2 - X_1) \qquad (14)$$

where θ_1 is the trajectory angle given by the velocimeter reduction data at the chosen initial point and $a \cdot \cos \alpha'$ is used as the multiplier of all X' terms.

The form factor, i_G, relative to the chosen drag function is

$$i_G = W/C_G d^2. \qquad (15)$$

These computations should be performed for each round of the test and the mean i_G and the standard deviation determined. If i_G differs greatly from 1, computations based on a different drag function should be tried.

If i has been determined at impact only, it is practical to consider that it pertains to that range for the muzzle velocity obtained. If intermediate values of i have been determined, it is still practical to list the value against slant range to the computed point even though the value might vary with range or the value may be listed against the angle α for the muzzle velocity. Computations based on velocimeter data should, preferably, be listed against the mean velocity, $(V_2 + V_1)/2$, when short increments along different parts of the flight path are used but, for convenience if projectile yaw is changing, can also be listed against slant range from muzzle.

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13. ABSTRACT

This Engineering Test Procedure describes test methods and techniques for determining Projectile Characteristics: Time of Flight; Form Factor; and Ballistic Coefficient. The techniques are intended for projectiles having essentially flat trajectories.

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